What Makes Games Challenging?
Considerations on How to Determine the “Challenge” Posed by an Exergame for Balance Training

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Source: http://www.sycor-aso.com/opencms/as/products_services/complementary_services/Telecommunication/
Motivation

Today

- Lack of exercise → health risks [WHO10, EC10]
- Sports reduce physical ailments [WHO10-1, ACSM11]

Challenge

- Exergames have small effects [BBC+08, KW10]
- Objective scientific methodologies [IQWiG11]
- Health technology assessment (HTA)

Idea

- Real-time “in game”- measurement
- Real-time “In game”- adaptation
Research Questions

RQ1: How can we assure the motivation of the players?

RQ2: How can we increase the training effects of Exergames?
State of the Art

Game Theory
- Attractivity [Malo82, YHL06]
- Flow [Csik75], Gameflow [SW05]
- Dual Flow [SHM07]
- Elderly [GeSM10, GLN+12]

Sport Games
- Wii Fit, DDR [BBC+08]
- Balance [KW10]

Interfaces & Sensors
- Cardio Training [SGYR09]
- Gait Rehab, Balance [GHS+11]
- Feedback [MHAE11]
- Game Experience (abbr. GX) [Nac09]
- Vital Parameters [SHM07, SGRY09]
- Stroke Rehabilitation [AHJS09]
**Concept: Adaptation Model for Exergames**

### Adaption Fields
- Hardware / Physis
- Game Experience
- Training
- Software

### Focus
- Adaptive Software
- Gaming
- Training

<table>
<thead>
<tr>
<th>Adaptive</th>
<th>System</th>
<th>User</th>
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<tbody>
<tr>
<td></td>
<td>Software</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Gaming</td>
<td>• Attractiveness</td>
</tr>
<tr>
<td></td>
<td>• Training</td>
<td>• Effectiveness</td>
</tr>
<tr>
<td>Static</td>
<td>Vital Sensors</td>
<td>Vital Status</td>
</tr>
<tr>
<td></td>
<td>• Electronics</td>
<td>• Vital Status</td>
</tr>
<tr>
<td></td>
<td>• Mechanics</td>
<td>• Performance</td>
</tr>
</tbody>
</table>

### Publications:
[HGG+11]
Concept: Adaptation Layers

Act
- Training / Playing
  - Training
  - Performance Test
  - Analyze
  - Adaptation
  - Modification

Measure
- Performance Test
  - Force
  - Endurance
  - Data Analysis
  - Training Settings
  - Setting Modification

Analyze
- Data Analysis
  - Initial Setup Calculation
  - Control Parameters

Adaptation
- Training Settings
  - Control Parameters

Modification
- Setting Modification
  - Hardware

Physis/Hardware
- Training / Playing
  - Strength
  - Movements
  - Force
  - Endurance

Game Experience
- Game Experience Measurement
  - Questionnaire
  - Video Analysis
  - BCI / EEG
  - Game Experience
  - Metrics
  - Game Adaptation
  - Challenge
  - Curiosity
  - Arousal
  - Gameplay Modification
  - Game Type
  - Graphics
  - Style

Training
- Performance Measurement
  - Power
  - Movement
  - Heart Rate
  - Intensity
  - Difficulty
  - Fitness

- Data Analysis
  - Parameter Adaptation

- Game Adaptation
  - Actuators
  - Game Objects
  - Game Control

Publications: [WH13]
Concept: Conditions and Metric

Conditions
- Game Experience Models
- Training Plans

Metric
- Keep Game Experience
- Improve Training Effects

Concept
- Adaptation
Concept: Formal Hypothesis

\[ \sum_{i=1}^{n} a_i(c_1, e_2, p_3) = M \times T = Q \]

- **Parameter**
  - GX Theory
    - Dual Flow
    - Attractivity
  - Training Guidelines
    - Cardio Training
    - Interval
    - Fall Prevention
    - Balance
- **Relation**
  - Adaptation
  - Measurement
- **Output**
  - GX Assessment
    - UX Rating
    - Fun
  - Performance Metrics
    - Cardio Training
    - Heart Rate
    - Fall Prevention
    - Stability
  - Health Status
  - Usage Frequency & Duration

- \( a = \text{Attributes of a single game} \)
- \( c, e, p = \text{Effects of one attribute (cognitive, emotional, physical)} \)
- \( M = \text{Motivational effects (positives affects, correlate with usage)} \)
- \( T = \text{Training effects} \)
- \( Q = \text{Quality (achievements of objectives)} \)
Concept: Parameters

Conditions
- GX Theory
  - Dual Flow
  - Attractivity
- Training Guidelines
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  - Interval
  - Fall Prevention
  - Balance

Interdependencies
- Parameter
  - Flow
  - Challenge
  - Workload
  - Clear Goals
  - Focus
  - Single Task
  - Control
  - Empowerment
  - Immersion
  - Awareness
  - Training Load
  - Exertion
  - Range
  - Speed
  - Resistance
  - Reaction
- Relation
  - Emotional Feeling
  - Cognitive Load
  - Physical Performance
  - ...
- Output
  - GXQ
  - Mimic
  - EMG
  - EEG
  - GSR
  - Respiration
  - ECG
  - Kinect
  - ArToolkit
  - Move
  - Razor
  - Hydra
  - Balance Board
  - VO₂max
  - ...

Metric
- GX Assessment
  - GX Rating
  - Fun
- Usage Frequency & Duration
- Performance Metrics
  - Cardio Training
  - Heart Rate
  - Health Status
  - Fall Prevention
  - Stability
  - Fall Risk

Adaptation
Measurement
Concept: Parameters

Conditions
- GX Theory
  - Dual Flow
  - Attractivity
- Training Guidelines
  - Cardio Training
  - Interval
  - Fall Prevention
  - Balance

Interdependencies
- Parameter
  - Clear Goals
  - Focus
  - Single Task
  - Feedback
  - Immersion
  - Control
    - Challenge ➔ Training Load
  - Skills: Flexibility
    - Speed
    - Strength
    - Coordination
    - Endurance

- Relation
  - Emotional Feeling
  - Cognitive Load
  - Training Success ➔ Physical Performance

- Output
  - GXQ
  - Mimic
  - Iris
  - VO₂max
  - EMG
  - EEG
  - GSR
  - Respiration
  - ECG
  - Kinect
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  - Move
  - Razor
  - Hydra
  - Balance Board
  - ...
Concept: Adaptation & Personalization

A: Asset Configuration
- Configuration of objects and interactions

C: Control Adaptation
- Relation between physiological measurements and control of the game

D: Difficulty Adaptation
- Adaptation of the game environment
- Estimation of user behavior
Concept: Asset Configuration

Object Types
- Player
- Target
- Enemy

Game Environment
- Obstacles

Design
- Graphics
- Sound

Interaction
- Position/Speed
- Physics/Al
Concept: Control Adaptation

Interaction
- Position/Movement
- Physics/AI

Control
- Physiological Reaction
- Sensor (S)
- Signals (s)
  - e.g. Heart Rate, Force, Speed
- $A = I(s)$
- Reactions
  - e.g. Height (h), Speed, Acceleration

![Diagram showing the interaction between control and game elements](image)

$\text{Signal} & \quad \text{Time [s]} \\
\hline
\text{h} & \quad \text{h}_1 & \quad \text{h}_2 \\
\text{y} & \quad \text{x,t} \\
\text{T} & \quad \text{E} & \quad \text{O}
Concept: Difficulty Adaption

Game Objects
- Area (A)
- Start (S) → Player’s Position
- Target (T)
- Enemies (E)
- Obstacles (O)
- Ground (G)
- Distance (D)
- Paths (P)

Game Structure
\[
A = \begin{pmatrix}
    a_{00} & \cdots & a_{m0} \\
    \vdots & \ddots & \vdots \\
    a_{0n} & \cdots & a_{mn}
\end{pmatrix}
\]

\(\forall a_{mn} : a_{mn} \in \{S, T, E, O, G\} ; m, n \in \mathbb{N}_0\)

\(\exists! a_{xy} : a_{xy} = S\)

\(\exists! a_{xy} : a_{xy} = T\)

\(D(a_{xy}, a_{u,v}) = \sqrt{(x-u)^2 + (y-v)^2}\)

\(S_{xy} \rightarrow S_{x'y'} : (x' = x) \lor (y' = y)\)

Strategies
- Shortest Path (P₁)
- Avoid Enemies (P₂)
- Easiest Path (P₃)
Difficultly Adaption: Balance Training

Metrics

- Center of Pressure
  \[ \text{COP} = \{x, y\} = \left\{ \frac{(F_2 + F_4) - (F_1 + F_3)}{\sum F_i}, \frac{(F_1 + F_2) - (F_3 + F_4)}{\sum F_i} \right\} \]

- Anterior-Posterior Stability Index
  \[ \text{APSI} = \sqrt{\frac{\sum (0 - Y)^2}{\text{Samples}}} \]

- Medio-Lateral Stability Index
  \[ \text{MLSI} = \sqrt{\frac{\sum (0 - X)^2}{\text{Samples}}} \]

- Overall Stability Index
  \[ \text{OSI} = \sqrt{\frac{\sum (0 - Y)^2 + \sum (0 - X)^2}{\text{Samples}}} \]

- Area of Sway
  \[ \text{AS} = (x_{\text{max}} - x_{\text{min}}) \times (y_{\text{max}} - y_{\text{min}}) \]

- Sway Path
  \[ \text{SP} = \sum_{i=1}^{n-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2} \]
  \[ \Rightarrow \sum_{i=1}^{n-1} |\tilde{p}_i - \tilde{p}_{i+1}| \]
Prototype BalanceFit

Experience

- Low initial skills $\rightarrow$ sensitivity
- Low initial performance
- Safety $\rightarrow$ standing frame
- Physical ailments
- Visual accessibility
- Risk of social exclusion

$\rightarrow$ Long term usage

Publications: [GHS+11]
BalanceFit: Asset Configuration

Hypothesis:

- The emotional design of the environment is reflected in their Game Experience Rating

Setting

- Two games, same gameplay, different emotional design. I.E. friendly vs. melancholy.

Outcome

- planned
- → prove effects for exergames
BalanceFit: Difficulty Adaptation

Hypothesis:
- New levels (curiosity) increase perceived game experience

Setting
- 10 Level, 50 Level
- Exclusion of simple levels (time limit)

Outcome
- Elderly are curious for new game elements
- Curiosity is important to keep a game challenging

→ How can we realize automatic difficulty adaptation?

Publications: [HGWS12], [HGS13]
Experimental Setting

Hypothesis 1: Level features influence motivation.
Hypothesis 2: Level features influence the perceived difficulty.
Hypothesis 3: Level features influence performance.

Hypothesis 4: Goal setting influences motivation, perceived difficulty and performance.

Independent Variables
- The length of the shortest path
- The number of orientation changes
- The number of bottlenecks
- The length of open curbs
Experimental Setting

Dependent Variables

- Motivation (subjective) Motivation Questionnaire (FAM, Rheinberg, Vollmeyer & Burns, 2001)
- Performance (objective): needed time to reach the goal

Control Variables

- Subjectively perceived level difficulty („subjective mental effort questionnaire“ SMEQ, Zijlstra & Van Doorn, 1986)
- Change of affects after each single level („Self-Assessment Manikin“ SAM, Bradley & Lang, 1994)
- Technology-Acceptance („Technology-Acceptance-Model“ TAM, Davis, 1985) n=47

Participants

- age: 18-42 Years (M=24,13, SD=5,48)
- 33 Students of Psychology, 9 Students of Psychology in IT
## Results

<table>
<thead>
<tr>
<th></th>
<th>Motivation</th>
<th>Difficulty</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
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<tr>
<td>Shortest Path</td>
<td>0</td>
<td>0</td>
<td>***</td>
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<tr>
<td>Orientation Changes</td>
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<td>**</td>
<td>***</td>
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<tr>
<td>Bottlenecks</td>
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<tr>
<td>Open Curbs</td>
<td>**</td>
<td>0</td>
<td>***</td>
</tr>
</tbody>
</table>

*- := p<=.1;  
** := p<=.01;  
*** := p<=.001;  
o := p>.01.
Discussion

Criticis

- Selected Levels Features and Definitions
- Number of investigated levels
- Characteristics of Levels

- High Standard Deviation → maybe an „individualized“ view is better
Maze Generation

Assumption
- Challenge is related to difficulty
- Difficulty depends on the possible tracks
- Difficulty depends on the selected tracks

Approaches
- Teleological vs. Ontogenetic

Personalisation
- Shortest path
- Avoid holes
- Prefer walls

Results
- Complexity
- Number of different levels
- Difficulty precision
Evaluation: Difficulty Adaptation

Runtime Comparison

<table>
<thead>
<tr>
<th>Method/Size</th>
<th>9x9</th>
<th>17x9</th>
<th>17x17</th>
<th>25x17</th>
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</thead>
<tbody>
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<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
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<tr>
<td>BS Partition</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
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<tr>
<td>Room Combine</td>
<td>-</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Set-Holes</td>
<td>3</td>
<td>30</td>
<td>242</td>
<td>817</td>
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<tr>
<td>Evolutionary</td>
<td>332</td>
<td>1086</td>
<td>3554</td>
<td>7554</td>
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Number of Different Levels

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<tbody>
<tr>
<td>Grid</td>
<td>48</td>
<td>737</td>
<td>993</td>
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<td>BS Partition</td>
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<td>Set-Holes</td>
<td>534</td>
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<tr>
<td>Evolutionary</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>
Difficulty Metrics

- Loss rate depends on the selected path
- Same values for instability \( p_{wall} = 0.99, p_{free} = 0.5 \)
- Path 1 (left): Loss rate 69.4%
- Path 2 (center): Loss rate 26.5%
- Path 3 (right): Loss rate 7.1%

No terrain weights

\[ w_{max} = 100, f_{decr} = 0.7, \]
\[ d_{max} = 2 \]

\[ w_{max} = 100, f_{decr} = 0.7, \]
\[ d_{max} = 2, f_{wall} = 0.1 \]
Questions & Contact

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References 1


References 2


References 3


[Nac09] Lennart Nacke, Scientific Measurement of User Experience in Interactive Entertainment Blekinge Institute of Technology School of Computing., 2009

References 4


